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H02M 3/158

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(56) Documents Cited
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(58) Field of Search
UK CL (Edition O) **H2F FXS FXT FXX**
INT CL^6 **H02M 3/10 3/125 3/135 3/137 3/139 3/142 3/145 3/155 3/156 3/157 3/158**

(54) **Boost Converter**

(57) A boost converter comprises a boost inductor L_B, a primary switch T_1, an output stage including a first capacitor C, a first diode D, for isolating the output stage, a secondary switch T_2 in parallel with the primary switch, and a turn-on inductor L_{TO}. A second diode D_4 and a second capacitor C_2 are arranged in series with the boost inductor L_B, such that the second capacitor C_2 is charged by current previously flowing through the primary switch T_1 when the primary switch is turned off, and subsequently discharged by current previously flowing through the secondary switch T_2, when the secondary switch is turned off. The turn-on inductor LTO may be connected between the boost inductor L_B and the first diode D (Figs 10-12). Diode D_4 may comprise three diodes (Fig 12).

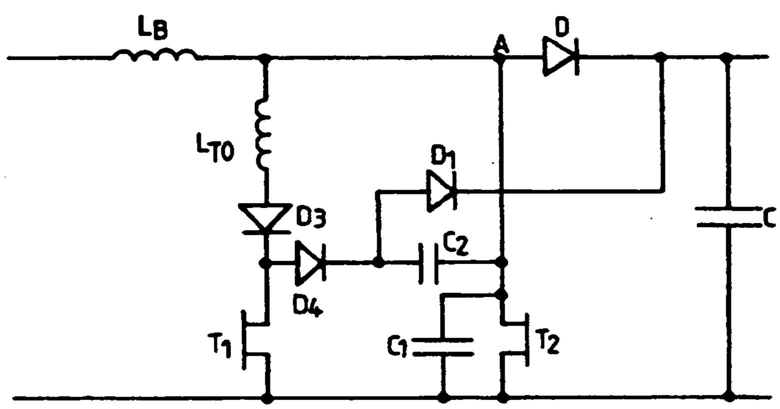

FIG.9

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

The claims were filed later than the filing date within the period prescribed by Rule 25(1) of the Patents Rules 1995

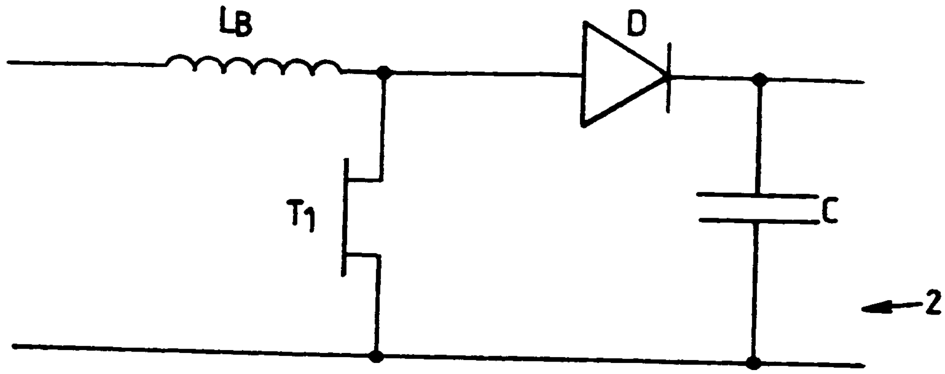


FIG.1

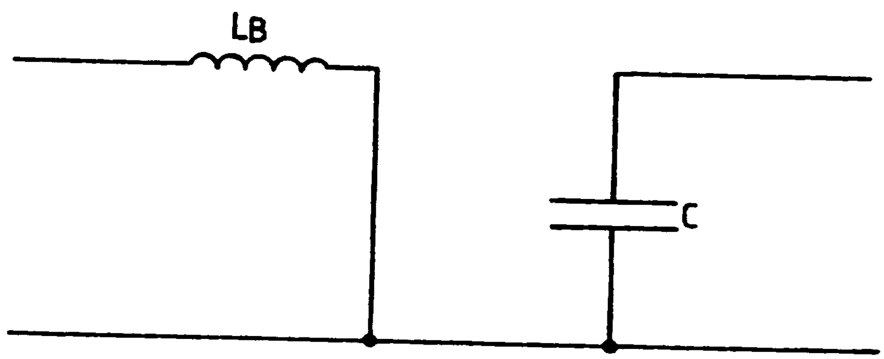


FIG.2a

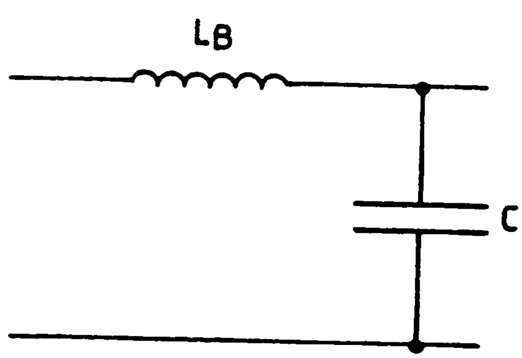


FIG.2b

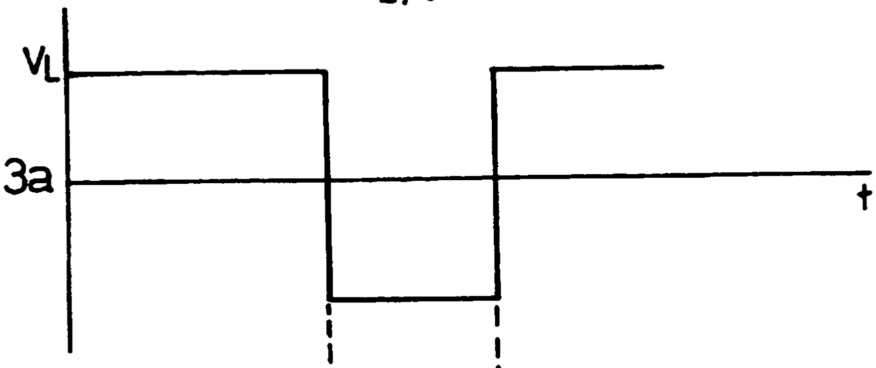


FIG.3a

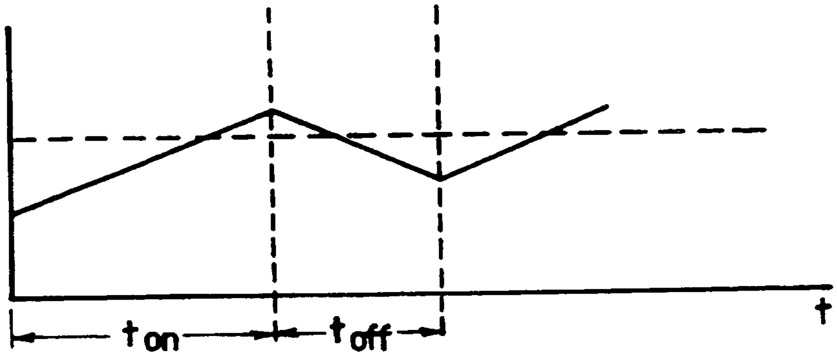


FIG.3b

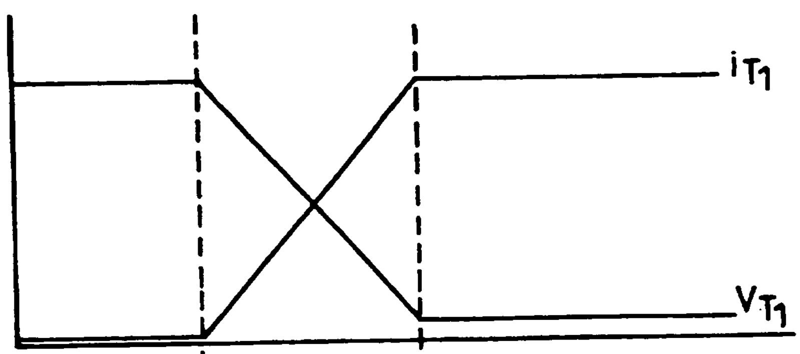


FIG.4a

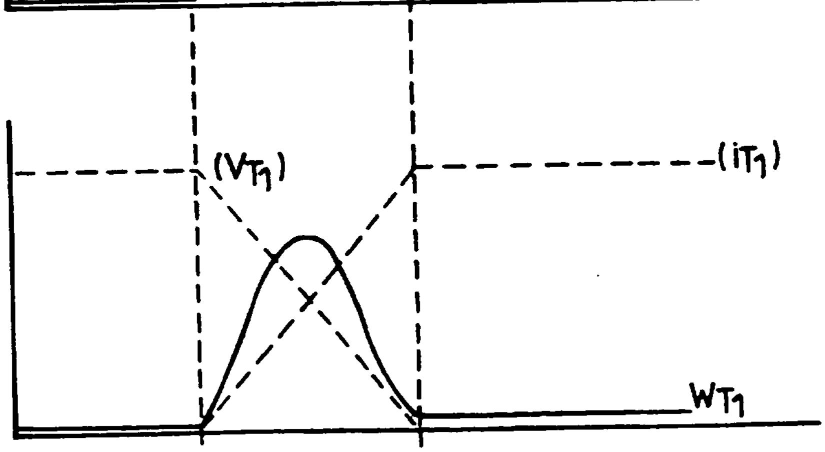


FIG.4b

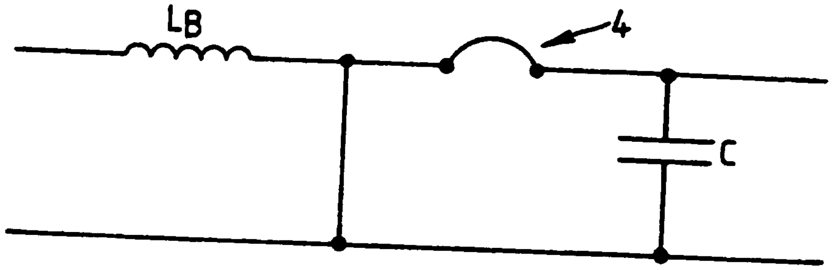


FIG.5

FIG.6a

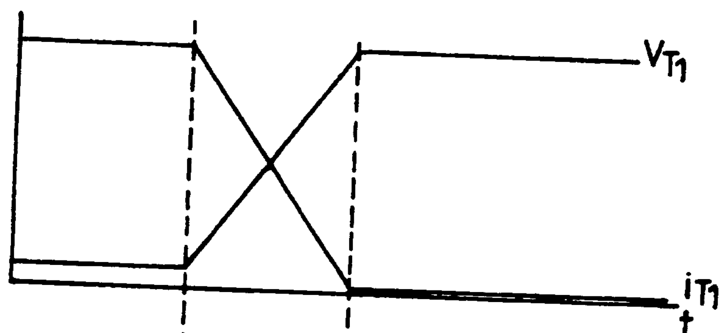


FIG.6b

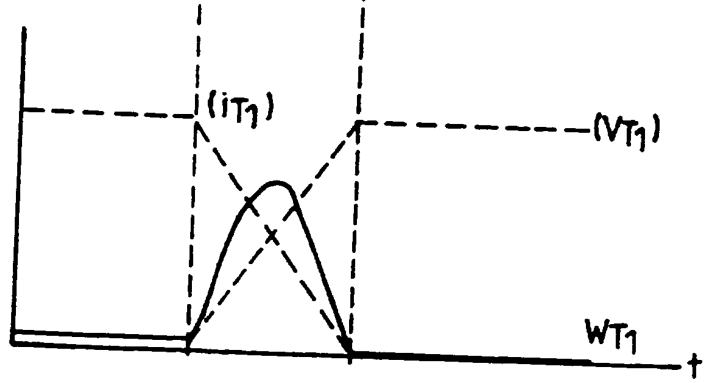
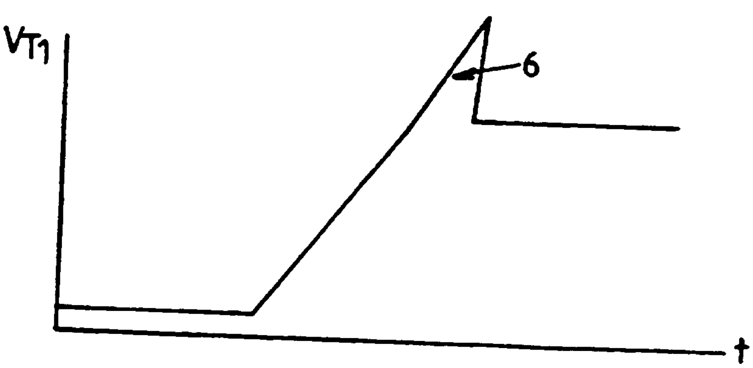


FIG.7



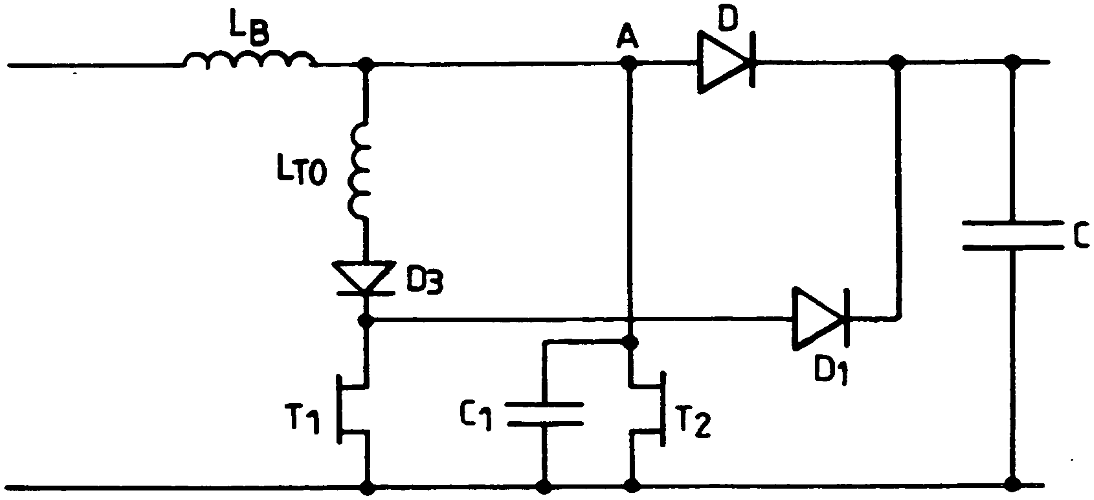


FIG.8

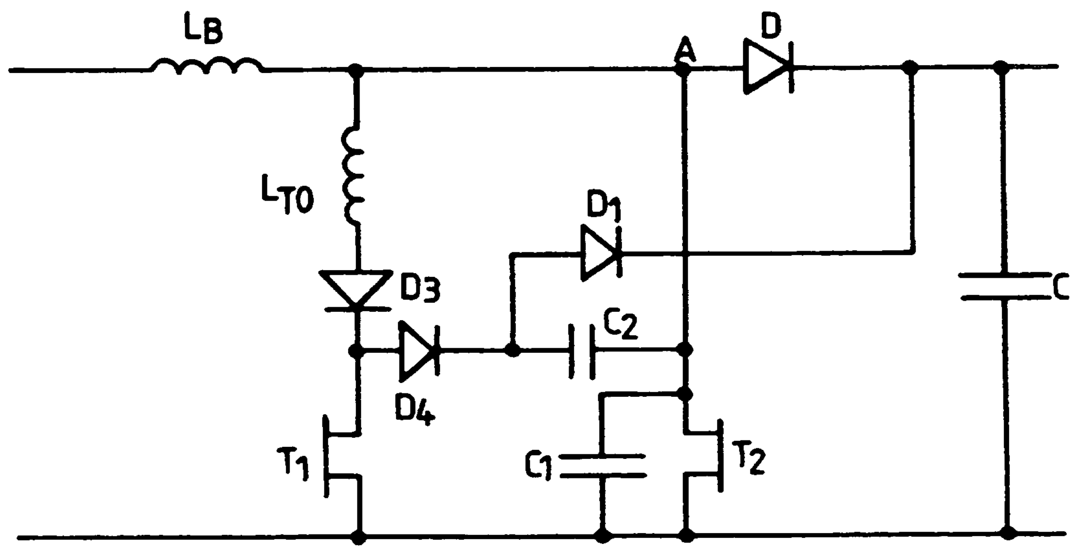


FIG.9

FIG.10

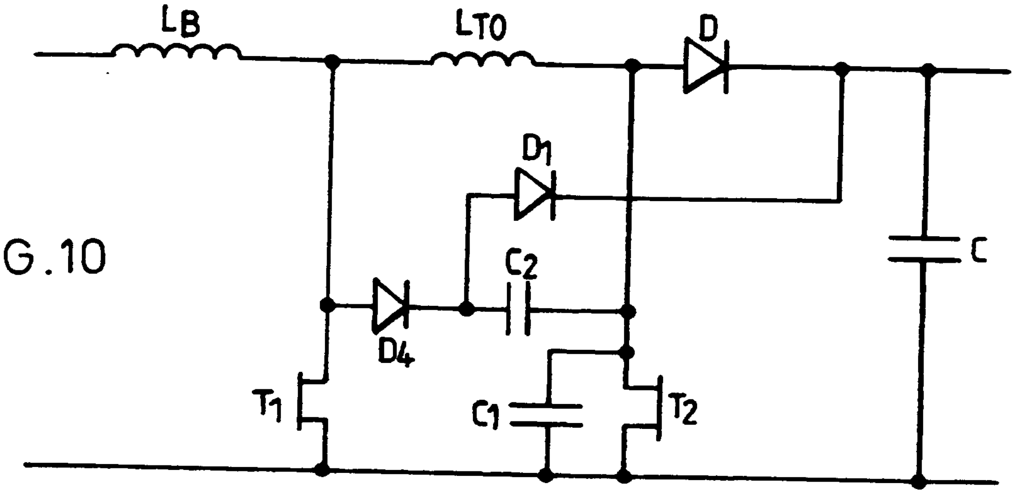


FIG.11

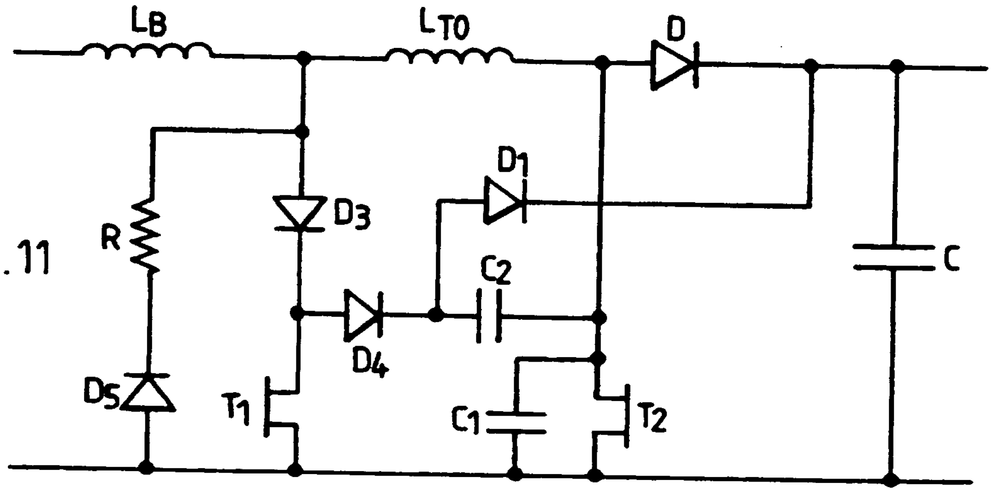


FIG.12

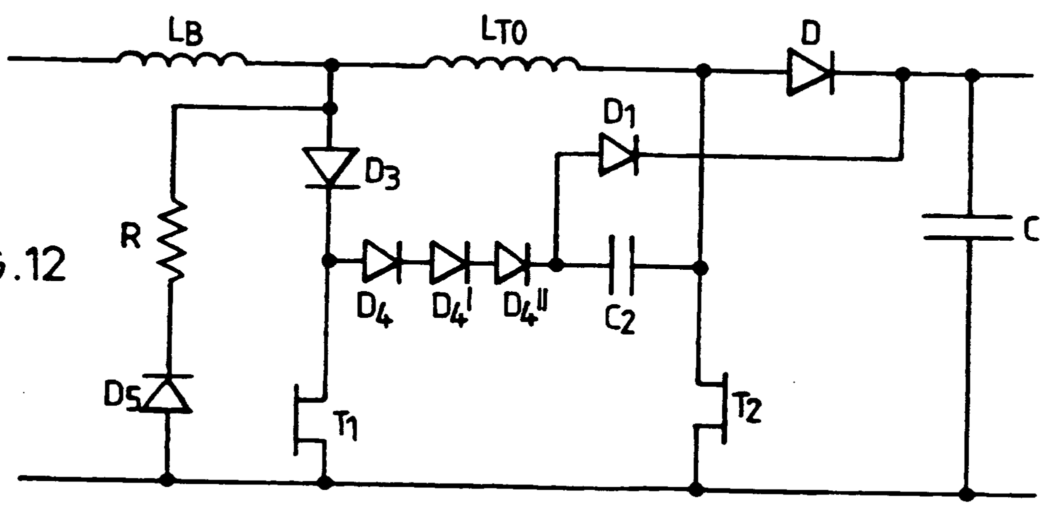
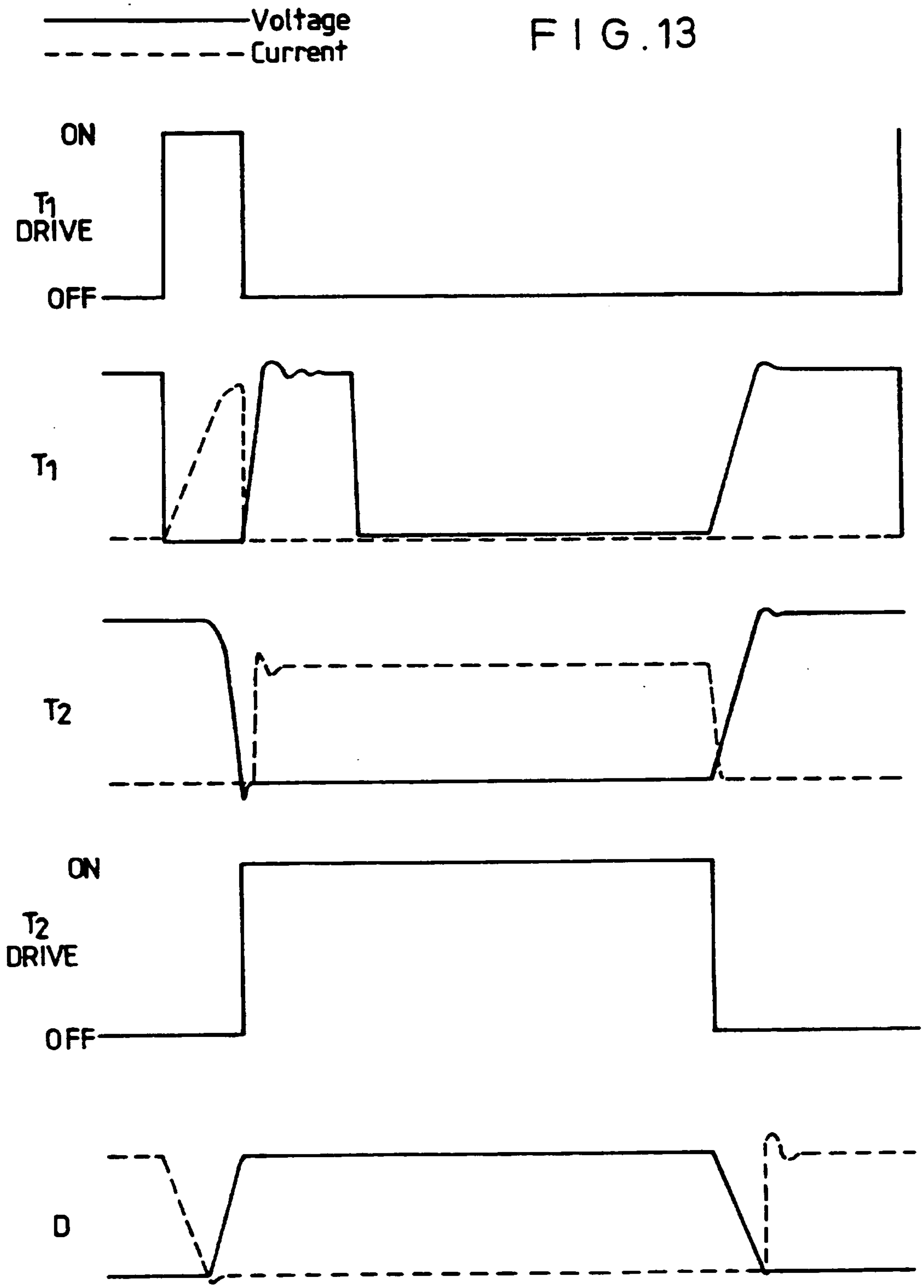


FIG.13



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BOOST CONVERTER

This invention relates to a so-called "boost converter" or "step-up converter".

A boost converter is essentially a form of switch-mode power supply. Switch-mode power supplies have conventionally been used as compact DC sources for providing a constant and a controllable output voltage with minimal ripple over a wide range of load currents. They are normally suitable for operation from a variable source.

Boost converters can be employed for a wide range of applications, including computers, regulated DC power supplies and the regenerative braking of DC motors. Primarily, a boost converter is intended to provide an output voltage which is greater than the supply voltage.

Figure 1 shows a circuit diagram of a conventional boost converter 2, in which transistor T_1 acts as a switch. Figure 2a shows a circuit equivalent to the circuit of Figure 1, when the switch T_1 is switched on. When the switch is on, the diode D is reversed biased, thus isolating the output stage. The input therefore supplies energy to the inductor L_B. Figures 3a and 3b respectively shown the voltage v_L across and the current i_L through the inductor against time. In these figures, period t_{on} represents a period during which the switch is on. Here it can be seen that when a voltage v_L is applied across the inductor, the current i_L through it gradually increases.

Figure 2b shows a circuit equivalent to the boost converter circuit when the switch T_1 is switched off. In this condition, the output stage receives energy from the inductor L_B as well as from the input. Figures 3a and 3b show that, during the period t_{off}, the current across the inductor decreases.

It has been found that problems exist with this conventional form of boost converter.

Figure 4a shows the current and voltage through the switch T_1 whilst it is actually turning on. It will be seen that the drop in voltage and the rise in current is not immediate. Consequently power W_L is dissipated in the transistor, as shown in Figure 4b. This energy is dissipated as heat, which is undesirable not only as wastage, but also because the circuit components must be arranged to allow the heat to be dissipated safely.

In addition, during the switching on of the switch T_1, the diode D remains a conductor and acts as a short circuit for a very short period (approximately 50-100 ns). This is shown schematically in Figure 5, where the short circuit is designated 4. This results in an additional current in the switch T_1 until the diode D has time to turn off.

When the switch T_1 is turned off, the current flows via the diode D to the capacitor C and starts to decay, as explained above. The voltage across the capacitor C is higher than the voltage applied at the input.

Figure 6a shows the voltage v_{T1} across the switch T_1 and the current i_{T1} through the switch T_1 during the period when the switch is actually being turned off. It can be seen that the voltage does not rise immediately, and the current takes some time to decay. As with the switching-on process, power W_{T1} is dissipated in the switch T_1, as shown in Figure 6b. This represents a further loss of energy, dissipated as heat.

In addition, for a short period, the diode D is an open circuit and so a high voltage appears across the switch T_1 for a period of approximately 20 ns before the diode D is turned on. This is represented in Figure 7, where the voltage spike caused by the high voltage is designated 6.

It can, therefore, be seen that the conventional boost converter suffers from the following problems:

(i) High turn-on losses;

(ii) A short circuit caused by the diode recovery immediately after turn-on;

(iii) High turn-off losses; and

(iv) A high voltage spike following turn-off, occurring before the diode is turned on.

The voltage spike during the diode turn-on represents an unnecessary stress on the switch T_1.

The power losses not only waste energy but also require sympathetic circuit components and circuit layouts, all of which represent unnecessary and undesirable costs.

In view of the above-discussed problems associated with the conventional boost converter, a modified converter, as illustrated in Figure 8, has been proposed. This arrangement includes an inductor L_{TO} for removing the turn-on losses.

The circuit functions as follows. When the switch T_1 is turned on, current builds up in the turn-on inductor L_{TO}. When the current in the inductor L_B equals the current in the turn-on inductor L_{TO}, point A resonates to 0 volts. This resonance is due to the effect of capacitor C_1 and the turn-on inductor L_{TO}.

When point A has resonated to 0 volts, switch T_2 is turned on and switch T_1 is turned off.

When switch T_2 is turned off, capacitor C_1 takes the turn-off losses in T_2.

Whilst this circuit goes some way towards addressing the problems identified with the conventional boost converter, it is to be noted, in particular, that this circuit does not address the turn-off losses in switch T_1. Consequently, the circuit still suffers from many of the problems and disadvantages experienced in the conventional arrangement.

The present invention sets out to overcome the above-discussed problems associated with the foregoing boost converter circuits.

According to the present invention there is provided a boost converter comprising:

a boost inductor,

a primary switch,

an output stage including a first capacitor,

a first diode for isolating the output stage,

a secondary switch in parallel with the primary switch, and

a turn on inductor, wherein

a second diode and a second capacitor are arranged in series with the boost inductor, such that the second capacitor is charged by current previously flowing through the primary switch when the primary switch is turned off, and subsequently discharged by the current previously flowing through the secondary switch when the secondary switch is turned off.

In such an arrangement, the second capacitor not only aids turn-off in the secondary switch, but also the primary switch.

A third capacitor may be provided in parallel with the secondary switch, for forming a resonant circuit in combination with the turn-on inductor.

The turn-on inductor may be arranged in series or in parallel with the second diode.

A third diode may be located in series with the primary switch. This serves to prevent reverse current from flowing through the primary switch.

Preferably, fourth and fifth diodes are arranged in series with the second diode. This can allow for particularly fast operation.

Embodiments of the present invention will now be described, by way of example, and with reference to the accompanying drawings in which:-

Figure 1 is a circuit diagram of a conventional boost converter;

Figure 2a is a diagram of a circuit equivalent to the circuit of Figure 1 when the switch T_1 is turned on;

Figure 2b is a diagram of a circuit equivalent to the circuit of Figure 1 when the switch T_1 is turned off;

Figure 3a shows the voltage across the inductor of the circuit of Figure 1 during a switching cycle;

Figure 3b shows the current through the inductor of Figure 1 during a switching cycle;

Figure 4a shows the voltage across and current through the switch of Figure 1 as the switch is turned on;

Figure 4b shows the power dissipated by the switch of Figure 1 as the switch is turned on;

Figure 5 is a representation of a circuit equivalent to the circuit of Figure 1 as the switch is turned on;

Figure 6a shows the voltage across and current through the switch of Figure 1 as the switch is turned off;

Figure 6b shows the power dissipated by the switch of Figure 1 as the switch is turned off;

Figure 7 shows the voltage of Figure 6a in more detail;

Figure 8 is a circuit diagram of a second known boost converter;

Figure 9 shows a circuit for a boost converter in accordance with a first embodiment of the present invention;

Figure 10 shows a circuit for a boost converter in accordance with a second embodiment of the present invention;

Figure 11 shows a circuit for a boost converter in accordance with a third embodiment of the present invention;

Figure 12 shows a circuit for a boost converter in accordance with a fourth embodiment of the present invention; and

Figure 13 shows voltage (solid lines) and current (dashed lines) waveforms of the embodiment of Figure 12.

Figure 9 shows a first embodiment of a circuit for a boost converter in accordance with the present invention. This circuit is generally similar to that shown in Figure 2 but includes an additional capacitor C_2 and a diode D_4 connected between the boost inductor L_B and diode D.

During the turning on of the transistor T_1, this circuit functions in exactly the same way as that shown in Figure 8. However, when switch T_1 is turned off, the current that was directed through T_1 is caused to charge capacitor C_2 to produce a positive voltage on its left-hand side, as viewed in Figure 9. This serves to eliminate the turn-off losses in T_1.

When switch T_2 is turned off, the current previously passing through this switch is directed to the capacitors C_1 and C_2. Point A then rises to the output voltage and effectively discharges capacitor C_2.

It can, therefore, be seen that both capacitors C_2 and C_1 aid the turn-off in switch T_2 while C_2 aids turn off in switch T_1.

The circuit is then ready for the next cycle.

Figure 10 shows a second embodiment of a boost converter circuit in accordance with the invention. In this embodiment, the turn-on inductor L_{TO} has been moved and is now situated immediately between the boost inductor L_B and diode D.

It has been found that diode D_3 from the circuits of Figures 8 and 9 has not always proved to be sufficiently quick and also causes oscillations due to reverse recovery problems. The embodiment of Figure 10 overcomes these undesirable characteristics.

When switch T_1 is turned on, current flows from the inductor L_B into the switch T_1, and current is drawn, in the opposite direction, from turn-on inductor L_{TO} towards the switch T_1. Typically the currents are each approximately 10 amps. Consequently, the current in the turn-on inductor L_{TO} decays to 0A when resonance commences.

Figure 11 shows a third embodiment of a boost converter circuit in accordance with the present invention. This circuit is generally similar to that shown in Figure 10, but includes diode D_3 to prevent any reverse current flowing through T_1. Diode D_5 and resistor R (rated at 0.5 W) provide an alternative path for the blocked current.

Figure 12 includes three diodes D_4, $D_{4'}$, $D_{4''}$ in place of the single diode D_4 of Figure 11. This is for extra speed. It will be noted that the capacitor C_1 has been omitted from the circuit of Figure 12. This is because capacitor C_2 aids the turn-off in T_2 and generally renders capacitor C_1 otiose.

Figure 13 gives the voltage and current waveforms of the embodiment of Figure 12. It can be seen that zero or very little current flows through the main switch T_2 during the period of the voltage transition and therefore T_2 is switched with effectively zero switching loss. There is similarly little loss due to the switching of auxiliary switch T_1. Therefore the circuit addresses the significant technical problem of switching losses, reducing them to practically zero.

Many further modifications and variations will suggest themselves to those versed in the art upon making reference to the foregoing illustrative embodiments, which are

given by way of example only, and which are not intended to limit the scope of the invention, which is determined by the appended claims.

CLAIMS

1. A boost converter comprising:

a boost inductor,

a primary switch,

an output stage including a first capacitor,

a first diode for isolating the output stage,

a secondary switch in parallel with the primary switch, and

a turn on inductor, wherein

a second diode and a second capacitor are arranged in series with the boost inductor, such that the second capacitor is charged by current previously flowing through the primary switch when the primary switch is turned off, and subsequently discharged by the current previously flowing through the secondary switch when the secondary switch is turned off.

2. A boost converter according to Claim 1, comprising a third capacitor in parallel with the said secondary switch, for forming a resonant circuit in combination with the turn-on inductor.

3. A boost converter according to Claim 1 or 2, wherein the turn-on inductor is arranged in series with the second diode.

4. A boost converter according to Claim 1 or 2, wherein the turn-on inductor is arranged in parallel with the second diode.

5. A boost converter according to any preceding claim, further comprising a third diode located in series with the primary switch.

6. A boost converter according to any preceding claim, wherein a fourth diode is arranged in series with the second diode.

7. A boost converter according to Claim 6, wherein a fifth diode is arranged in series with the fourth diode.

8. A boost converter substantially as hereinbefore described with reference to Figure 9; Figure 10; Figure 11; or Figures 12 and 13 of the accompanying drawings.